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Abstract : **This paper presents the emerging requirements users are imposing upon the evolving world of heterogeneous 4G mobile/wireless networks through their perception of final services. The mapping proposed in this paper groups together these user requirements in three main and distinguishable categories: service provision, connectivity, and adaptability and reconfigurability, by describing system concepts for each category from user terminal to network and services/applications.**

Keywords: QoS, IP networks, mobile/wireless networks, 4G systems, reconfigurability, adaptability.

I INTRODUCTION

The commercial success of 2G mobile networks and the growth rate of the Internet over the last decade have led the Information and Communications Technology (ICT) industry and research community to focus their effort towards an integrated framework that will provide a wider range of services to mobile users. Huge investments for R&D, spectrum allocation and deployment of 3G systems have been made, hence generating great expectations for revenues for all market players. However, the lack of access and location transparency, as well as of reconfigurability and adaptability capabilities, have proven to be a major shortcoming for the evolution towards a 'universal' 4G mobile/wireless networks. These impediments, which result in limited user friendliness in contrast to the open, easy-to-access and easy-to-use Internet paradigm, are motivating a research effort to alleviate the above-mentioned shortcomings prior to the commercial launch of all variations of 3G systems.

The combination of the shortcomings of 3G systems and the widely accepted fact that having insight into user requirements both informs more appropriate provision of services and uncovers reasons why they are not meeting their intended aims results in a clear need for a more detailed identification of end user requirements, and their mapping into system concepts as a start point for defining 4G communications systems. An example of this is the Wireless World Research Forum's Working Group 1, which aims at identifying the necessary issues to make beyond-3G wireless systems user-centred. On the other hand, the penetration of ICT services and technologies, the rapid development of the enabling technologies required for 4G and the user experience with current mobile services and fixed Internet [2] make future users likely to have strong expectations about the advantages of 4G mobile and wireless systems, resulting in user requirements being of key importance for their design.

In the context of the IST-ANWIRE[1] (**Academic Network for Wireless Internet Research in Europe**) project [1], we research user-centric expectations and requirements before wireless Internet and reconfigurable systems become technically and financially viable. In this paper we present a mapping of user requirements into the system concepts needed to support 4G mobile and wireless communication systems.

This paper is organized as follows. In Section II we present a mapping of user requirements into 4G mobile/wireless communications system concepts, grouped in the categories of service provision, connectivity and reconfigurability/adaptability, the most representative of which are described in Sections III to V. Finally, Section VI includes the summary of this paper and future work.

II. MAPPING OF USER REQUIREMENTS

Generally, end-users do not have a direct perception of the parameters of mobile/wireless networks, but of the quality of service (QoS) provided, user access and user terminal. Hence, it may be inferred that the user experience is global and

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holistic, involving and merging all the elements of mobile/wireless networks, terminals, services and applications. In other words, mapping of user requirements into system concepts is needed in order to design future 4G mobile/wireless communication systems that satisfy user expectations. Note that in this paper we do not consider subjective aspects that may influence end-user requirements, such as previous experience or expectations about services, since they cannot be effectively mapped.

User requirements can be classified according to various perspectives and metrics. Six generic areas of user requirements (*user interface, access, security, contents, mobility, and billin*g) are considered in this paper as a result of grouping together common user scenarios, and end-user requirements for systems beyond 3G identified by the research community [2, 3].

Figure 1 depicts the ANWIRE grouping based on the above-listed user requirements as well as their mapping into system concepts, grouped together in the categories identified in ANWIRE as shortcomings of 3G systems [1]: service provision, connectivity, and adaptability/reconfigurability. In Sections III to V, for each category, requirements will be described in a structural manner from user terminal to network and services.

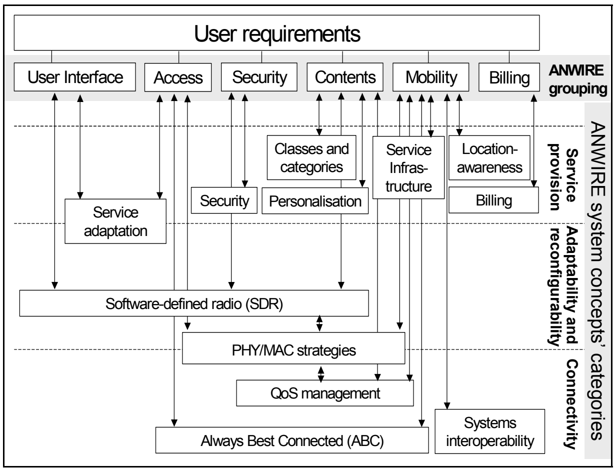

Figure 1. ANWIRE mapping of user requirements

We consider user interface as service personalisation and adaptation to terminal, and thus it is mapped in service provision and adaptability/reconfigurability categories. Then, access is mapped into the connectivity and service provision categories. (Note that subjective aspects on interface, such as intuitiveness or ease-to-use, and on the perception of access speed, depending on the task the user is completing and the stimuli s/he is receiving, are out of the scope of this paper). Security is mapped into adaptability/reconfigurability (secure Software Defined Radio, SDR) and service provision categories. Service and application contents are also mapped into these two categories, considering adaptability/reconfigurability as SDR contents. Mobility is mapped into the connectivity category, also considering location-awareness and infrastructure of service provision. Finally, billing is mapped into the category of service provision.

Due to the clear overlap of connection and adaptability/reconfigurability categories in terms of physical layers, PHY/MAC strategies are described in Section V. Seamlessly, service adaptation is described in the adaptability/reconfigurability section.

III. SERVICE PROVISION

The convergence of Internet with -4G systems will create a new market for mobile/wireless services, customizing the functionality of wireline Internet services for the needs of users connecting via wireless infrastructures and mobile terminals. A wide spectrum of new services will be offered; in this section we describe the related system concepts for service support and provision identified by ANWIRE, namely service characterisation, service infrastructure, security and billing.

A. Service characterisation

Services to be supported by 4G systems can be divided into three categories based on their nature [5]:

i. Communication-centric services cover direct contact and community-forming systems over networks.
ii. Transaction-centric services focus on the capability of conducting transactions with mobile/wireless handheld devices (terminals), encouraging mobile commerce.
iii. Content-centric services are focused on the delivery of content over mobile/wireless networks.

Content-centric services can be further divided according to the user demands they try to fulfil, into informational (location-aware information, e.g. news), entertainment (satisfaction of user's need for amusement, e.g. games) and organizational (functionalities of personal management applications, e.g. calendars) services.

Seamlessly, categories (i) to (iii) can be further characterised according to their offer of personalisation, context awareness and/or localisation. Personalisation services focus on adapting information by considering users' behaviour and interests, context-aware services examine the environment and react to changes, and location-based services rely on the fact that mobile/wireless network servers are able to determine the user terminal position. By combining positional mechanisms with location information, powerful, flexible personal information services can be developed.

Services may be as well subdivided into classes, according to their characteristics and performance requirements. Several bodies (3GPP, ITU-T, ETSI, UMTS Forum) have suggested classifications based on similar concepts, the most representative being 3GPP's conversational (e.g. speech), streaming (e.g. streaming multimedia), interactive (e.g. web browsing) and background (e.g. file download) service the traffic delay sensitivity. Conversational is the most delay-sensitive (even delay-variation sensitive) class, while background is the most delay-insensitive class. While conversational and streaming classes are mainly intended to be used to carry real-time traffic flows, interactive and background (lower scheduling priority) have looser delay requirements, providing nevertheless a better error rate. The main achievement of such a classification is that system concepts, distinguished by these classes, are clearly perceived by the end user, establishing a direct mapping between user requirements and system service requirements.

We now associate applications to each service, and characterise them according to service parameters. Figure 2 presents an analytical taxonomy of applications based on the IETF model (real-time and elastic), enhancing it through finer-grained conceptualisation, such as adding pre-emptive (discardable, in case of network congestion) and expendable (not subject to admission control) packet services through the use of the Flow label and Priority field in IPv6 headers and dropping policies [1], and through distinguishing mobility-independent and dependent services, further divided into mobility independent predictive (reliable delay bounds in case of hand-over or hand-off) and mobility independent guaranteed (as long as user's mobility is inside his/her characteristics) [4].

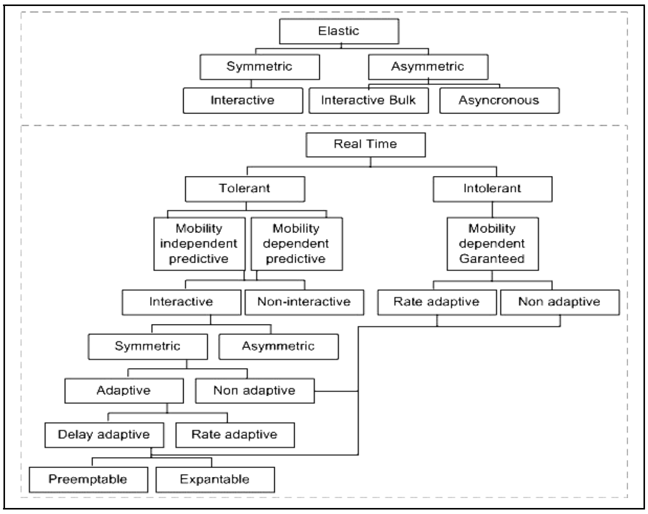

Figure 2. Taxonomy of applications

B. Service infrastructure

As mobile/wireless devices become more popular, the heterogeneity of terminals and the capacity mismatch between clients and servers are expected to grow [5]. To cope with this, service provision infrastructures should meet the requirements of optimising the client-server wireless communication and contents to different terminal capabilities, enlarging the volume of useful content by enabling service personalisation, localisation and information filtering, and guaranteeing high availability and robustness, as well as incremental performance and capacity scalability with an expanding user base.

These requirements cannot be met by traditional infrastructures, such as web servers and proxies. Instead, *'intermediary systems'* [6] should be used, which are more complex, distributed and programmable infrastructures that can play the role of content provider. These *'intermediary systems'* are also able to provide reconfigurability or programmability, and they can be used as infrastructures for developing various 4G services. Three main characteristics of *'intermediary systems'* can be considered:

i. Intermediary software architecture (distributed, programmable and configurable).
ii. Interaction between intermediary and client and origin-server systems (synchronous/asynchronous, push/pull).
iii. Functionality of the intermediary system (e.g. customisation, filtering, caching).

Also intermediary systems can provide configurability or programmability. Intermediaries can be uses as infrastructures upon which various services can be developed. Tuning an intermediary infrastructure can provide different levels of abstraction and flexibility

C. Security and billing

In future 4G mobile/wireless networks, communicating parties will provide credentials for authentication without awareness of each other; hence, user authentication and access network authentication should be based on a public key certificate, a common, always-accessible trusted third party and a Public Key Infrastructure for certificate management [7]. With the increasing volume of commercial information, users will require stronger end-to-end security, and therefore new robust, less 'power-hungry' encryption techniques will be needed to secure communications and prove content encryption of both stored and removable data, such as smart cards containing user digital certificate needed for mobile commerce. Moreover, metadata protection, including confidentiality of identity, time and traffic, raises a question of finding a compromise between anonymity and accountability, and a need for new easy-to-use adaptability mechanisms. Location privacy should be as well provided through standardising mobile/wireless communications' resistance against eavesdroppers, and protection should be provided against different types of attacks, such as (distributed) denial of service, traffic deviation etc [1].

Concerning billing, it will reach an incredible degree of complexity in 4G mobile/wireless networks: variation of pricing, depending on combinations of time, traffic and servers load criteria, will be applied to different user modalities, with strict requirements, including user charging notification and coordination of billing authorities [1].

IV. CONNECTIVITY

Since users are willing to consume new services, as long as they enjoy the same characteristics as with mobile telephony [2], in the highly heterogeneous environment foreseen for 4G mobile/wireless networks similar levels of connectivity (e.g. *'anytime, anywhere, anyone')* are essential even in situations of low coverage and high mobility.

A. Always Best Connected concept

We define Always Best Connected (ABC) as a system capability ensuring that users can always be connected to services in the best possible way, integrating connectivity prioritisation (management of user access to priority services) [1, 8]. Since users will have access to 4G devices with different capabilities at different times, and to various wireless access networks and priority services, this *'best connection'* will not be static, which poses the following requirements for 4G mobile/wireless systems [1]:

i. For user terminals:

   a. Maintain simultaneous associations with different network service providers (NSP).
   b. Set constraints as preferences for network selection, like cost, QoS or data capacity.
   c. Indicate local network range for interoperability.
   d. Allow user access to priority services without affecting calls in progress in the network.
   e. Be programmable, through reconfigurability.
   f. Be multimode, for automatic hand-off (Figure 3).

ii. For 4G mobile/wireless networks:

   a. Include ABC-related primitives, such as available NSPs, network quality or hand-over.
   b. Allow dynamic programmability of network elements for location/connection management.
   c. Provide preferential management to priority services, even with network congestion.
   d. Support of unicast and multicast services.
   e. Intelligent management mechanisms, e.g. roaming brokers or transactional setup of connections.

iii. For services:

   a. Scale and adapt dynamically to minimize control and interactions, optimising the use of resources.
   b. Be transparent to underlying network technology.

B. QoS management

A number of 4G services are expected to impose an important requirement for a generic notion of QoS, apart from subjective perception of QoS by end users, which is heavily dependent on their previous experiences and expectations (subjective), not considered in this paper.

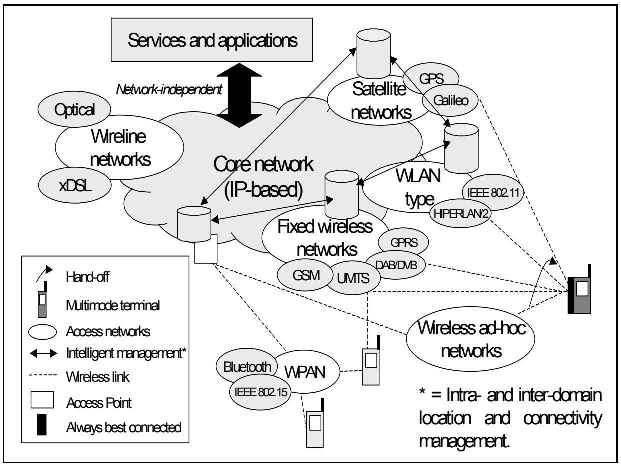

Figure 3. Always Best Connected scenario

In addition to any QoS configuration activity during connection establishment, run-time monitoring and dynamic reconfiguration are important capabilities in the service provision phase. The aim of QoS management is then to adapt to changing conditions during runtime and to maintain committed QoS levels or to react upon changes in these levels, allowing graceful service degradation and operation over best-effort network environments, a key requirement for service continuity across the widest range of network infrastructure. Dynamic QoS reconfiguration constitutes an important requirement that is yet to be addressed in the emerging Open Service Architecture framework of 3GPP. As an example (Figure 3), in the context of GSM/UMTS networks, QoS configuration involves resource reservation through SS7-based signaling, whereas in IP networks, both quantitative and qualitative QoS should be provided through the IntServ and DiffServ frameworks.

In the latter, both static and dynamic Service Level Specifications (SLS) will be involved, although a suitable negotiation protocol is not available yet. The use of standardised QoS specification, SLS and negotiation protocols is necessary to establish the amount of network resources available, based on which the appropriate service adaptation can be provided.

C. Interoperability

Since 4G services will rely on heterogeneous wireless access networks (Figure 3), interoperability, considered as the combination of direct compatibility between user and service infrastructure and the extension of features across the service provider and local network domains, is also a connectivity key requirement, posing the following extended requirements with respect to ABC [1]:

i. For user terminals:
   a. Multi-mode capabilities.
   b. Software/hardware reconfigurability as described in Section V.B.
   c. Autoconfiguration (almost transparent to the users).

ii. For 4G mobile/wireless networks:
   a. Support of smooth vertical hand-over (e.g. 802.11 to UMTS), through the asynchronous primitives mentioned in Section IV.A (ii. a), allowing handover-aware applications to be written easily.
   b. Flexible and modular QoS support as described in Section IV.B.
   c. Unified authentication as described in Section III.C.
   d. Programmability of network elements, as described in Section IV.A (ii b).

iii For services:
   a. Transparent, dynamic adaptation regardless of network technologies, except QoS [8,9].
   b. Independence from signaling protocols, i.e. independence from the transport technology; a connectivity management system covering intra- and inter-domain operation could make it possible to change transport mechanisms and networks independently from services.

V. ADAPTABILITY AND RECONFIGURABILITY

A 4G system should be self-adaptive to abstract any variants tending to modify the end-to-end communication, preventing the user from feeling changes, even in the event of failures or insertion of new service adaptation, software defined radio, and physical and MAC layers (PHY/MAC) strategies for reconfigurability [10].A. Service adaptation

Service adaptation can be distinguished into service-to-terminal (STA) and service-to-network (SNA) adaptation. As for STA, the proliferation of Internet access devices imposes that services be accessible from any terminal, and thus be adaptable to the needs, capabilities and limitations of the delivery environment. Different access modalities range from home appliances to mobile terminals, while different connectivity modes range from high bandwidth modems to mobile/wireless networks. In this direction, service management (Figure 4) should provide multiple user views altered based on the user's terminal and the network capabilities, taking into account the dynamic creation and adaptation of terminal device profiles to transcode user interface components for appropriate presentation.

Concerning SNA, adaptation between the service and the network should ideally be bi-directional. Therefore, adaptation triggered by the network would consist of sending notifications of changes affecting service delivery through a network performance monitoring system [1], whereas adaptation triggered by services could be a dynamic request of enhanced (also /reduced, network resources are very valuable and often limited thus should be used "economically" as needed by a particular service task) network QoS (within the permitted range for the user), which would result in the reconfiguration of the involved connection. Because heterogeneity of QoS models in different network technologies should be hidden from services, a middleware layer would be required in order to map an abstract service QoS request into the appropriate network QoS class [1].

B. Software Defined Radio(SDR)

SDR is one of the most important new technologies for future 4G mobile/wireless systems, since it will allow terminals to be reconfigured at any communication layer, i.e. not only the air interface but also the entire communication method might be changed by reconfiguring both the software and (to a limited extent) the associated hardware, so that the result best suits the user requirements [11]. By using complex databases, probably from outside the terminal, containing different parameters (e.g. terminal's hardware limits, software features or available services), the software reconfiguration block (Figure 4) would produce instances of new software downloadable to a terminal, and then would reconfigure the terminal's hardware to run in this quite new configuration. On the other hand, secure software download is a key SDR component based on customisable setting of cryptographic components, and including elements like approval and verification of downloaded software, preventing usage of unapproved or illegally created software etc [12].

C. PHY/MAC strategies for reconfigurability

The approach taken in the physical-layer architecture design is crucial to define the adaptability and reconfigurability, since 4G networks will need to adapt several dynamic environment factors, such as changing channels and traffic, power saving modes or applications. Moreover, adaptability/ reconfigurability in 4G should include a wide variety of communication.

To reconfigure any part of the PHY/MAC layers it is necessary for the network to have some intelligence and reconfiguration control. A Global Intelligent Reconfiguration Control (GIRC) module is needed to manage every time the different parameters involved in the environment changes, such as the user environment, network environment, and radio environment. Here, intelligence decides what part(s) of the network should be reconfigured, based on the relevant information supplied to it, and then get the reconfiguration controller to implement these decisions in the appropriate way.

The cross-layer approach aims at introducing some degrees of knowledge, introducing optimisation between the physical and link layer and taking into account both PHY and MAC layers. This design is in its beginning and encompassing the physical resources is critical as regards the choice of appropriate and skill parameters that could serve as agents for carrying the information between the communication levels [10, 13].

In recent years, it has become more and more evident that elements as smart antennas, multiple input multiple output (MIMO) elements [13, 14] and scalable detections will play an important role in modern wireless systems and they will be the main physical layer support resources for achieving the Always Best Connected strategy in 4G communication systems.

The cross-layer architecture must introduce some degrees of acknowledgement and optimisation between PHY and MAC layers through

i. PHY-MAC dialogue [10] to achieve the reconfigurability process, through parameter exchange. The MAC layer provide the diversity of exploitation information (time, frequency, code or space), and the PHY layer monitoring parameters such as SNIR, BER, battery life channel state information (CSI) etc.(Figure 4).
ii. Reconfigurable hardware through flexible algorithms by using different complexity trade-off [10, 13, 15].

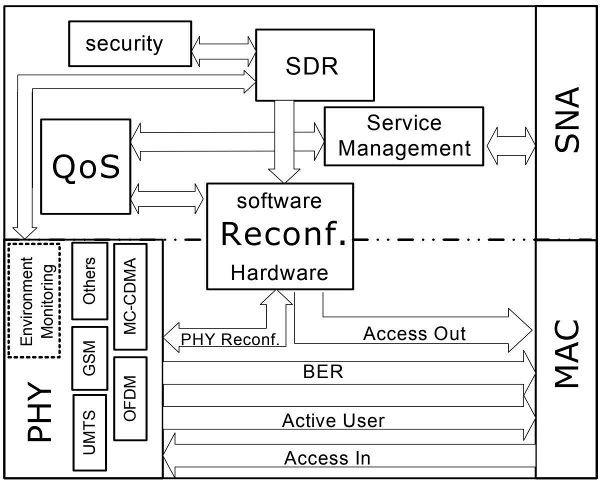

Figure 4. Logical architecture of a 4G terminal

VI. SUMMARY AND FUTURE WORK

Considering the evolution of the quality of service (QoS), enabled for 4G mobile/wireless networks, this paper summarises studies to date on the QoS concept itself undertaken within the IST-ANWIRE thematic network project [1,8]. It addresses the objective systems concepts of the QoS from the viewpoints of the various wireless network 'requirements'. In particular the different concepts of adaptability/reconfigurability, and service provision, which will respect users' aspirations and viewpoints, are considered primary with given priority for QoS requirements upon the heterogeneous 4G networks.

In brief form, we provide an initial proposal for a type of reference terminal and network architecture with the main parameters and agents of reconfigurability/adaptability, connectivity, and service provisions involved in the different layers for QoS, with a proposal for the development of the physical layer support with a 'cross-layer' concept, as well as to skirt round the state-of-the art and research challenges in the components of various entities of the enabling technology in the other layers.

Future related work includes updating this mapping as user-focused scenarios and requirements are expanded [3], as well as considering user perspective for the research integration performed by the IST-ANWIRE project: mainly in areas of wireless Internet and reconfigurability.

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